Studies on Sonar Clutter and Reverberation

John R. Preston
Applied Research Laboratory
P.O. Box 30
State College, PA 16804
phone: (814) 863-1310 fax: (814) 863-8783 email: preston@ciao.arl.psu.edu

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LONG-TERM GOALS

The long-term goals of this effort are to:

- Assess capability of directional arrays for inversion and reverberation studies
- Characterize acoustic clutter in a manner that will lead to its mitigation
- Improve geo-acoustic parameter extraction from reverberation data
- Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

OBJECTIVES

The objectives of this effort are to:

- Use and continue to collect cardioid data from FORA and the NURC cardioid array, conduct cross frequency correlation studies of scattering features to assess the utility of this technology for reverberation and clutter analysis both in the cardioid frequency band and at lower frequencies.
- Continue the use of K-distribution-based techniques of Abraham to statistically characterize the various types of clutter seen on STRATAFORM including bio-clutter data from FORA.
- Continue validation and improvement efforts on a new reverberation model and the automated geo-acoustic parameter extraction technique from reverberation data.
- Operate, maintain and improve FORA hardware and data acquisition systems. Help plan and participate in ocean experiments in support of sea floor scattering, bio-clutter studies and other ocean reverberation experiments.

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APPROACH

The four linear sections and the cardioid array section at the head of the new Five Octave Research Array (FORA) offer a novel new way to study reverberation and scattering in shallow water. A limited data set from this cardioid array was collected in the 2003 Acoustic Clutter Experiment in STRATAFORM off New Jersey. Recently, additional cardioid data was collected from the FORA array during OREX-05 and from the NURC array during the 2004 Boundary Characterization sea trial. These data are being used to improve and test the beamforming algorithms and data processing tools needed for future experiments. The NATO Undersea Research Centre has shown examples of left-right rejections in excess of 15 dB on its cardioid array (Hughes,NURC Rpt SR-329). The PI has verified that similar performance is observed using FORA during the 2003 Acoustic Clutter experiment. It has been observed that often the same reverberation and/or clutter features can be observed over a wide range of frequencies. An objective for the reverberation studies is to correlate the high frequency unambiguous feature or scatterer information from the cardioid data with the lower frequency bearing ambiguous information.

The PI completed efforts to statistically characterize the clutter seen on STRATAFORM in the 2001 and 2003 Acoustic Clutter Experiments using methods developed by Abraham. Results, showed many data segments of matched filtered amplitudes examined to be non-Rayleigh and that the bistatic data were significantly more non-Rayleigh than the monostatic data. The non-Rayleigh behavior is consistent with the spikiness seen in much of the Acoustic Clutter 2001 polar displays. Much of the observed statistical differences between various data segments can be explained by considering differences in multipath, amounts of bottom insonification and the overall sound speed structure. This work has recently been extended to include a statistical characterization of the STRATAFORM area for the 2003 data (see section on work completed).

Using incoherent bottom reverberation, an inversion scheme to estimate of bottom parameters has been developed using a simulated annealing (SA) technique [1]. This permits near real-time higher quality performance predictions to be made. Specially designed cost functions have been developed and used to evaluate the results. Using the work of Hamilton [2] and guidance from C. Holland, the PI developed a constrained SA algorithm, which narrows the solution search space. The procedure currently uses the reverberation computations of the Generic Sonar Model (GSM) [3] and the bottom loss estimates of ORCA, but a new reverberation model is being developed (see below). A multi-frequency optimization capability is part of the algorithm. The SA inversion methodology has been used on a variety of data [4-6]. The scattering strength models developed by Jackson et. al. (for example [7]), have also been incorporated into the automated inversion scheme. With the high quality of geo-acoustic ground truth available from the STRATAFORM and Malta Plateau areas, these data sets are ideal for testing such inverse schemes. In the past the towed array based inversion algorithms developed by the PI used bearing ambiguous diffuse reverberation data and therefore were not able to map extracted geo-acoustic parameters in more than a spatially averaged sense when reverberation was anisotropic. Cardioid data now available will remove the unnecessary averaging, leading to higher quality estimations.

A new range-dependent reverberation model based on normal modes is currently in development together with Dale Ellis of DRDC and will serve as a new forward model engine for the simulated annealing based inversion scheme already in use. Westwood's ORCA model is used to compute the eigenvalues and eigenfunctions [8] with coupling of range independent segments to be based on Evans Couple model [9]. Real 3–D effects for data taken on horizontal line arrays using directional sources already incorporated into normal mode based models like OGOPOGO by Ellis [10], have been added

to the new model and bistatic capability is currently being developed and tested. Validation efforts with the PI's model vs. the Ellis models show excellent agreement for simple test cases from the upcoming Reverberation Modeling Workshop (see Fig. 2 below).

Future experimental efforts to study clutter and reverberation will depend heavily on the ONR Five Octave Research Array (FORA) at Penn State, which is maintained by ARL-PSU. FORA was built under a recent DURIP award. The FORA was used in NRL's OREX05 and in the M.I.T./ONR's NPAL-04 and 2003 Acoustic Clutter experiments. Previously, the FORA also completed T-Mast 02, (July 2002), where a significant amount of data was collected using it as one of the primary receivers. Maintenance and system upgrades require some time on the part of the PI and in particular time for a technician to keep the FORA ready for duty. With the concurrence of ONR, improvements/ repairs to FORA are usually required between sea trials.

WORK COMPLETED

Under cardioid data analysis, from a paper submitted to the Journal of Oceanic Engineering: Some directional characteristics of observed clutter and reverberation were presented using new cardioid receiving line arrays. It was shown that the cardioid arrays break the left-right ambiguity for reverberation sources above ~600 Hz. Broadband data were taken from two recent experiments. One was the 2004 Boundary Characterization Experiment near the Malta Plateau. That experiment was lead by the NATO Undersea Research Centre (NURC). The area is rich in clutter objects like wrecks and mud-volcanoes and has some sub-bottom features that may be important. Sources were monostatic coherent pulses and SUS. The receiver was the NURC cardioid array. The other experiment was ONR's 2003 Geoclutter effort to study shallow water bottom reverberation and clutter in the STRATAFORM area off New Jersey. That experiment was lead by M.I.T.. Sources were bistatic coherent pulses. The receiver was the Five Octave Research Array (FORA). The STRATAFORM area is known to have benign surface morphology but strong clutter is observed. Some highlights of the reverberant returns from that area were discussed that include the correlation of returns from probable fish schools. Examples from the data analysis were presented using a cardioid beamforming algorithm developed by researchers at NURC but normalization for the algorithm was derived by the PI and some frequency limitations were noted. Also a constrained simulated annealing inversion technique was applied to the directional reverberation data. A two-layer fluid model of the bottom was assumed. The algorithm is best at estimating compressional speeds, layer thickness and attenuations. Extracted bottom parameters at the site were compared with independent inversion results from Holland. Inverting reverberation from directional arrays leads to better quality results since unlike standard line arrays, the reverberation data apply to only one bearing along the seafloor.

The PI also helped plan and then participated in NRL's OREX-05 experiment designed to measure bottom loss, local scattering, diffuse reverberation, pulse spreading and water-column volume scattering off the Oregon coast. This data set represents a much more complete cardioid data collection effort using the FORA. In this time period, additional new pieces of software were developed by the PI to process cardioid data from the FORA.

Under statistical characterization of clutter from a 2006 ASA paper: In 2003 ONR sponsored the Acoustic Clutter Experiment to study shallow water scattering and clutter in the STRATAFORM area off New Jersey. Sources were bistatically received coherent pulses. The receiver was the Five Octave Research Array (used horizontally). The STRATAFORM has benign surface morphology but contains many sub-surface features. MIT researchers have shown fish to be a primary source of the observed clutter and reverberation. K-distributions with their shape and scale parameters, were used to describe

non-Rayleigh behavior. Statistical characterization was presented vs. location. The 'bandwidth' effect was shown where the shape parameter first decreases inversely proportional to bandwidth but then increases back toward the Rayleigh distribution at higher bandwidths. The shape parameter estimates for the 2003 data were well fit by an elongated patch model of Abraham and Lyons. It was shown that shape parameter estimates are about the same for the 2003 and 2001 data taken in the same area. The main differences between the data sets were that the typical scatter sizes/strengths seem to have increased. This is consistent with observations by Nero of NRL and by MIT researchers of higher and more concentrated fish populations observed in 2003.

The FORA is intended as the primary receiver in a new experimental component of an initiative to study fish schools with remote sensing in the Gulf of Maine. This work was written up in a Feb. 2006 article in Science featuring images using FORA. The PI has also spent some effort in overseeing the 'care and feeding' of the ONR FORA at Penn State in preparation for the 2006 Gulf of Maine experiment. In addition, plans for a FORA refurbishment effort are being developed to prepare for the 2007 Wideband Clutter and Base07 Experiments.

Efforts to develop a range dependent normal mode based reverberation models have continued. ORCA is used to generate the eigenvalues and eigenfunctions for an environment and then modifications to Ellis' techniques have been used to build the reverberation model using Matlab. Some results will be presented at the upcoming Reverberation Modeling Workshop in the fall of 2006.

RESULTS

Below is a recent result showing reverberation using the cardioid array from FORA on data from the 2003 Acoustic Clutter Experiment. Figure 1 shows a polar display of bistatic reverberation from the New Jersey Shelf vs. angle and range. Data was collected on the FORA cardioid towed array in a 150 Hz band centered at 1325 Hz. Reverberation is color-coded vs. intensity using the PI's recently derived normalization for the Hughes cardioid beamforming algorithm. The source was an LFM pulse, 1 s in duration. Left-right ambiguity is broken by the cardioid beamformer and shows excellent left-right rejection on various clutter features that have been shown to be mostly from fish schools [11].

Figure 2 shows model-model comparison at 3500 Hz between the PI's new ORCA-Matlab based reverberation model and D. Ellis' NOGRP model for a downward refracting test case from the upcoming Reverberation Modeling Workshop.

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The new FORA and NURC cardioid arrays are exciting new tools for ocean acoustic researchers. A wide area-averaged bottom parameter estimation technique such as described above and that utilizes directional reverberation measurements could provide a quick way to estimate bottom parameters and hence give improved sonar performance estimates.

TRANSITIONS

Inversion techniques similar to those described above have recently been applied to select data from recent HEP experiments as part of ONR 6.2 efforts lead by Dr. R. Wayland in support of the TAMBDA program at NAWC. In addition, an effort is underway to incorporate the above inversion concepts and reverberation models into a multi-static parallel toolbox – an effort that is being led by J. Joseph at NAWC.

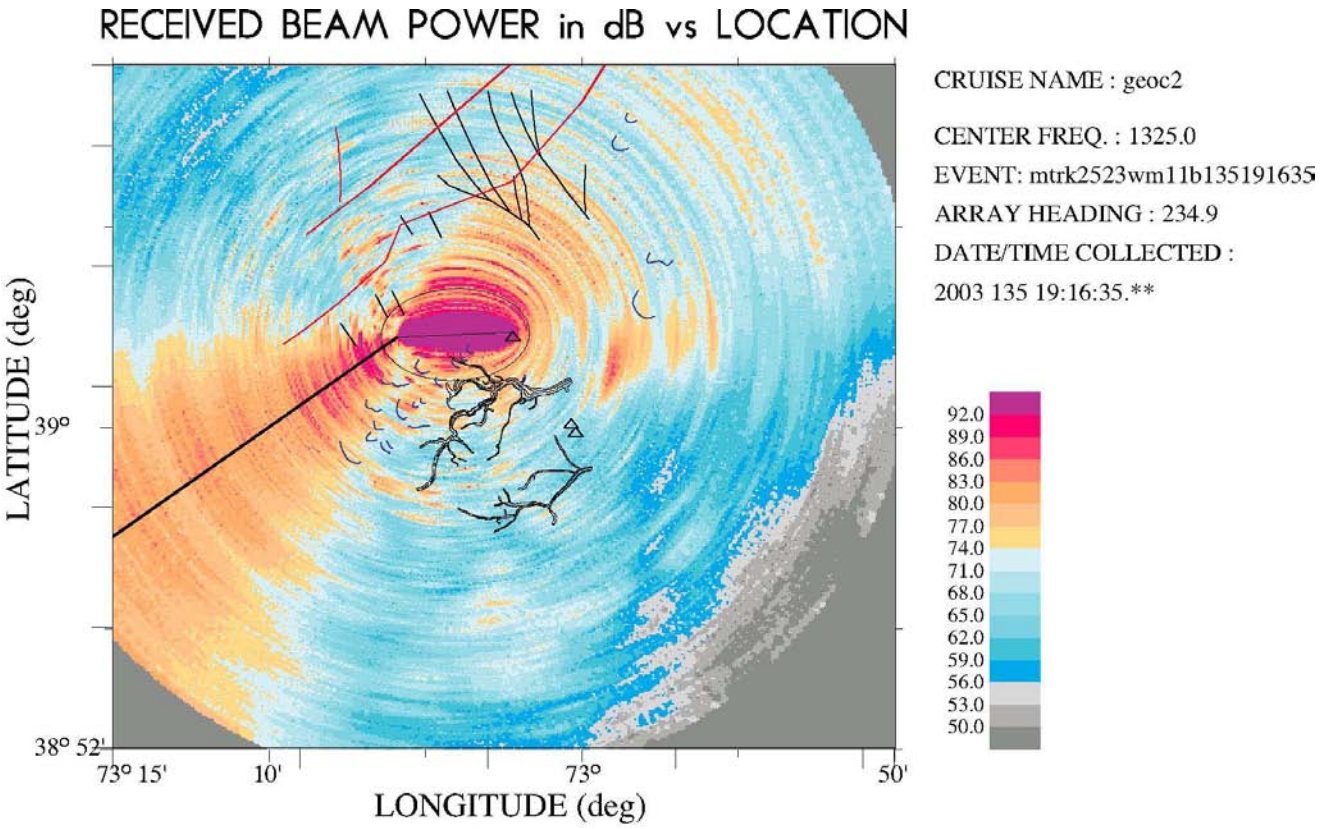

Fig. 1. Polar plot of the bistatic reverberation on the FORA cardioid array from a 1s LFM pulse near STRATAFORM, Site S2 in the 1250--1400 Hz band. The black line to the southwest indicates the array heading. The array is at the start if that line. The source is located at the right end of the horizontal line from the receiver (at the triangle). Levels indicated by color scale are in dB//1uPa^2/Hz. Left-right ambiguity is broken by the cardioid beamformer and shows excellent left-right rejection on various clutter features(most likely fish schools [11]).

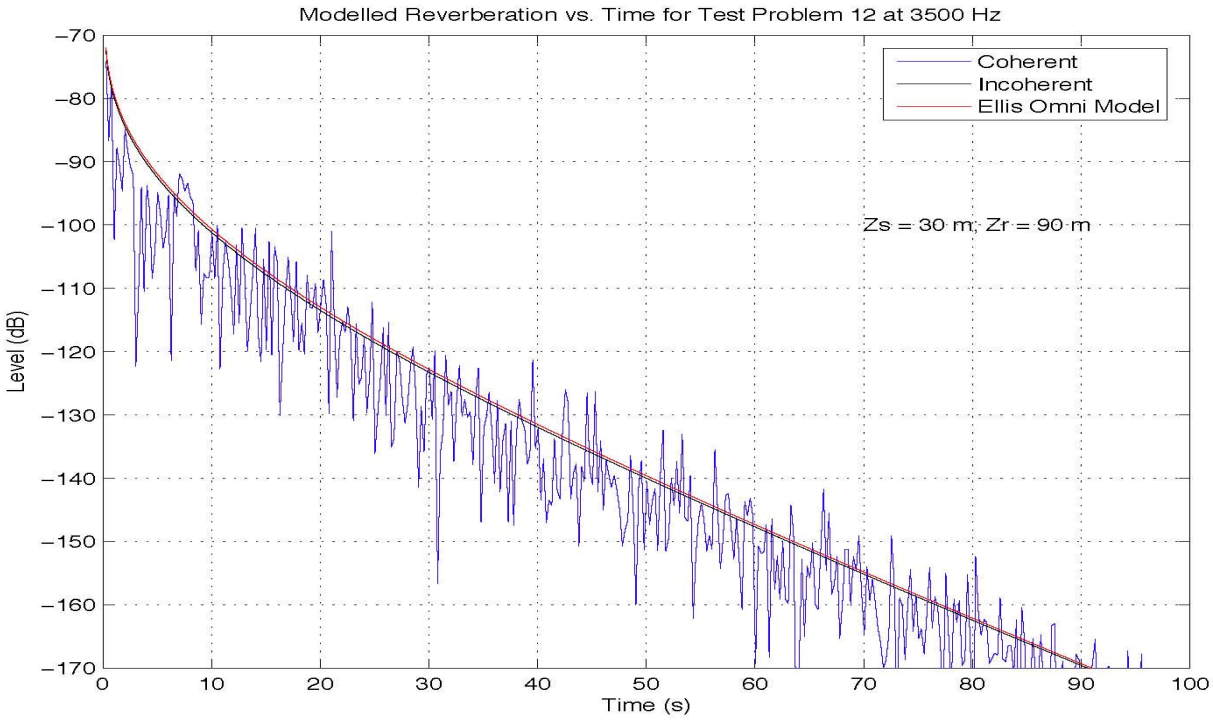

Fig. 2. Model-model comparison at 3500 Hz between the PI's new ORCA-Matlab based reverberation model and D. Ellis' NOGRP model for a downward refracting test case from the upcoming Reverberation Modeling Workshop.

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